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## The far-UV break in quasar energy distributions: dust?

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**Abstract.** A prominent continuum steepening is observed in quasar energy distributions near 1100Å. We review possible interpretations for the origin of the so-called far-UV break, putting emphasis on those that favor the emergence of an upturn in the extreme-UV.

### 1. Introduction

The spectra of quasars and Seyfert galaxies show strong emission lines superimposed onto a bright continuum. The continuum contains a significant feature in the optical-ultraviolet region, known as “the Big Blue Bump”. Due to the huge photoelectric opacity of the Galaxy, the Spectral Energy Distribution (SED) of the ionizing continuum, between the Lyman limit and the soft X-rays (EUV–X), is hardly known. Fortunately, owing to the redshift effect and the transparency of the quasar environment, it has been possible to infer the SED of quasars down to  $\sim 350\text{\AA}$ . Composite energy distributions were derived by Zheng et al. (1997) and later by Telfer et al. (2002) using archived HST-FOS spectra. Before averaging, each spectrum was dereddened for Galactic absorption as well as statistically corrected for the absorption due to intergalactic Ly $\alpha$  absorbers and Lyman limit systems.

A striking feature of the composite quasar SED is that a significant steepening occurs around 1100Å, leading to a far-UV powerlaw of index  $\nu^{-1.7}$  ( $F_\nu \propto \nu^{+\alpha}$ ). Korista, Ferland & Baldwin (1997) pointed out the difficulties of reproducing the equivalent widths of the high ionization lines of HeII (1640Å), CIV (1549Å) and OVI (1035Å), assuming a powerlaw as soft as  $\nu^{-2}$ . State of the art photoionization models favor a much harder SED, one that peaks in the extreme-UV beyond 22 eV (e.g. Casebeer, Leighly & Baron 2006; Korista et al. 1997; Baldwin et al. 1995). The far-UV break is clearly seen in individual spectra (see Binette et al. 2005: hereafter B05). The amount of steepening varies considerably from object to object. Binette & Krongold (2006) recently analyzed the spectrum of Ton 34 ( $z = 1.928$ ), which is the object with the steepest break known, with a far-UV behavior given by  $\nu^{-5.3}$ . However, strong emission lines of OVI and CIV are present. There is no generally accepted interpretation of the nature of the far-UV break. We review below possible absorption

mechanisms that would give rise to the break and at the same time allow the emergence of an upturn in the extreme-UV, in order that the ionizing SED be as hard as needed in photoionization calculations of the emission lines.

## 2. Possible causes for the UV-break

We hereafter assume that the far-UV break results from absorption and will consider two possibilities: (I)– H I [ $\text{Ly}\alpha$ ,  $\beta$ ,  $\gamma$  ... and bound-free] and (II)– interstellar dust. We will consider four locations for the absorbing medium: (i) intergalactic, (ii) local to the quasar ISM, (iii) accretion disk photosphere and (iv) accelerated outflow from quasars. The resulting eight cases are illustrated in Fig. 1 with labels 1–4 for H I and A–D for the dust. The aim is to resolve the problem of the ionizing SED, which appears to be too soft. Among the eight cases reviewed, some have the potential to resolve the softness problem, either because the local BELR sees a different SED (intergalactic absorption), or because the absorption in the UV is followed by a flux upturn at higher energies.

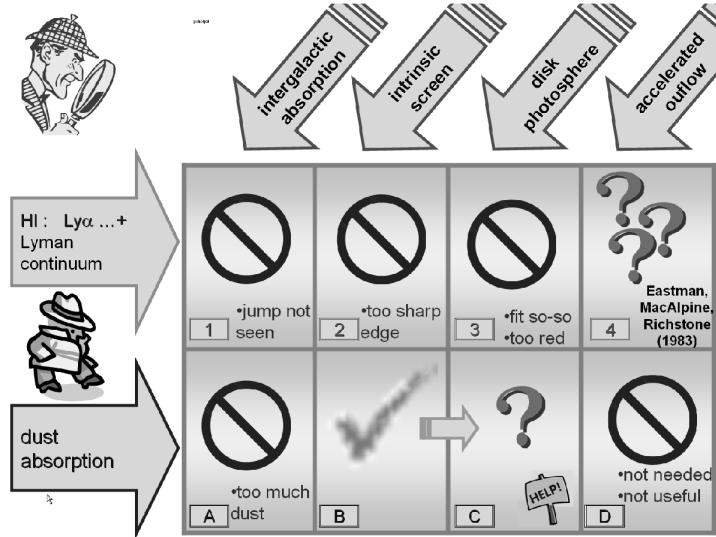


Figure 1. Diagram illustrating the 8 cases due to either H I or dust absorption. Barred circles denote rejected or unpromising cases.

Case 1 – Binette et al. (2003) studied this possibility. They assumed an H I behavior (as a function of  $z$ ) proportional to the gas density expected from the warm-hot intergalactic medium. Although they could reproduce the TZ02 composite, they rejected this possibility, since their model predicted a jump in flux blueward of  $1216\text{\AA}$  (observer-frame) that is not observed.

Case 2 – An absorber at the quasar redshift results in a sharp absorption edge at  $912\text{\AA}$  as well as in an  $\text{Ly}\alpha$  absorption line. Such pronounced and sharp features do not match the far-UV steepening discussed above.

Case 3 – State of the art ‘naked’ accretion disk (NAD) models predict a steepening (i.e. Lyman edge) near  $\text{Ly}\alpha$ . However, the far-UV break is not reproduced well by NAD models (c.f. Fig. 22 in Hubeny et al. 2000). The Lyman edge from a NAD model is not followed by a flux upturn at higher energies, hence the softness problem remains unresolved. The same may be said of the comptonized accretion disk model although in that case the UV break is well reproduced (Zheng et al. 1997).

Case 4 – Eastman, MacAlpine & Richstone (1983) could generate a steepening of the continuum by having absorptions clouds progressively accelerated up to  $0.8c$ . Exploration of a different behavior of the H I opacity with velocity would be welcomed, as these calculations might shift the break position to the observed value near  $1100\text{\AA}$  (instead of  $1216\text{\AA}$ ), and possibly produce a flux upturn beyond  $20\text{ eV}$ . Furthermore, by including He I opacity, such models might explain the curious dip observed at  $500\text{\AA}$  in one of the most studied quasar, HE 2347–4342 (see Fig. 2). Interestingly, both the  $1100\text{\AA}$  and  $500\text{\AA}$  breaks are blueshifted by comparable amounts with respect to rest-frame He I and H I  $\text{Ly}\alpha$  (at  $584\text{\AA}$  and  $1216\text{\AA}$ , respectively).

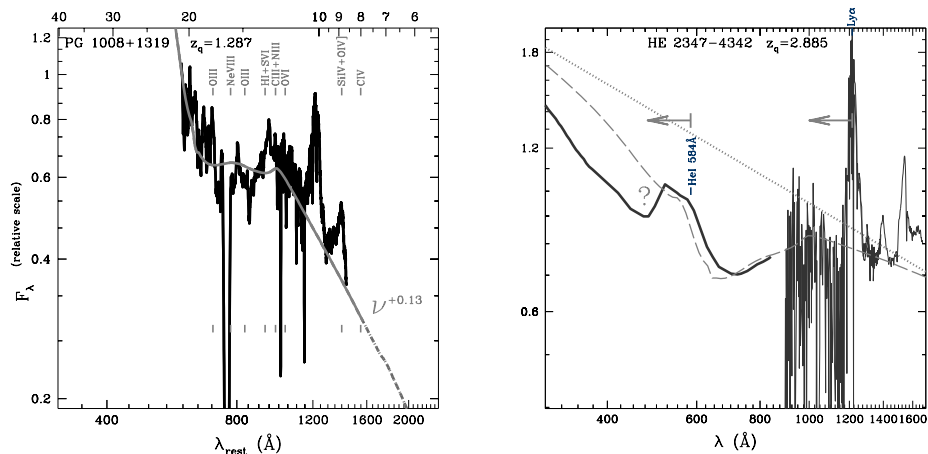


Figure 2. Left panel: rest-frame spectrum of PG 1008+1319 (black line). The silver line represents an absorption model assuming extinction by cubic diamonds and an intrinsic SED consisting of a powerlaw (dotted line). Right panel: spectrum of HE 2347–4342 (thick and thin black lines) extracted from Reimers et al. (1998). A powerlaw SED (dotted line) and a dust absorption model (dashed line) are also shown.

Case A – B05 studied the possibility of intergalactic dust consisting of nanodiamond grains (other dust compositions were unsuccessful). They could reproduce the dip displayed by the far-UV indices when plotted as a function of redshift. This possibility was rejected, since it required too much intergalactic dust ( $\sim 17\%$  of the cosmic carbon). It also required that only nanodiamond dust is formed.

- Case B – Assuming a nanodiamond dust component intrinsic to each quasar, B05 successfully reproduced the far-UV break observed in individual quasars of the TZ02 sample. The flux upturn taking place below  $650\text{\AA}$  in these models near allow the intrinsic SED to be much harder than indicated by extrapolating of the flux near the UV break. Such an upturn was identified in 4 quasar spectra. An example, PG 1008+1319, is shown in the left panel of in Fig. 1. From a spectrum that combines various archives, Binette & Krongold (2006) reported a far-UV rise in Ton 34. A 6th example is provided by HE 2347–4342 (see upturn shortward of  $700\text{\AA}$  in Fig. 2). Shang et al. (2005) explored the possibility of ISM and SMC-like extinction.
- Case C – It would be interesting to compute the SED emerging from a NAD photosphere that contains small amounts of nanodiamond dust. If the break is accounted for by dust, much harder (hotter) disk SEDs could be envisaged. Nanodiamonds have so far been identified in emission around 3 stellar disks. A large UV fluence may facilitate dust formation.
- Case D – We consider the hypothesis of an accelerating dust outflow not to be needed nor useful for the purpose of explaining the far-UV break.

### 3. Conclusions

We find that the three cases 4, B, and C are worth exploring further, as they may reconcile the observed downturn in the far-UV with the need of a harder SED to account for the high ionization emission lines. The exploration of absorption by an intrinsic crystalline carbon dust screen (case C) is at this stage the most developed hypothesis. We are currently exploring its consequences in the infrared and UV in order to provide ways to falsify such models.

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